DISTRIBUTED FILE SYSTEM

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"Hadoop" is a philosophy — a movement towards a modern architecture for managing and analyzing data. – Arun Murthy, Hortonworks, Cloudera, 2019.
The notion of time is an important concept in every day life of our decentralized "real world" - Friedemann Mattern.

What Comes Next?

byte

kilobyte

megabyte

gigabyte

??

???

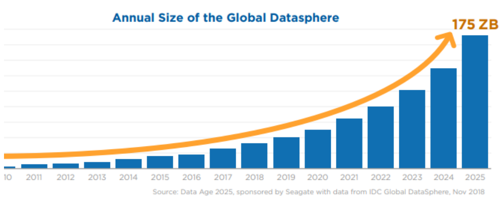
????

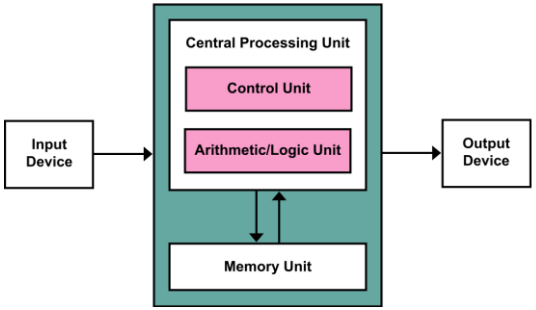
?????

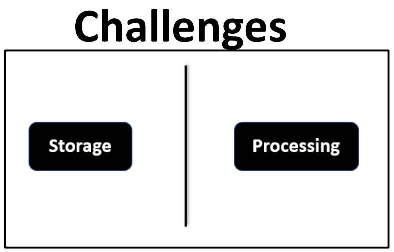
Sizes

Name	Size
Byte	8 bits
Kilobyte	1024 bytes
Megabyte	1024 kilobytes
Gigabyte	1024 megabytes
Terabyte	1024 gigabytes
Petabyte	1024 terabytes
Exabyte	1024 petabytes
Zettabyte	1024 exabytes
Yottabyte	1024 zettabytes

Recap

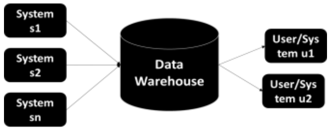

Annual Size of the Global Datasphere
175 ZB
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Source: Data Age 2025, sponsored by Seagate with data from IDC Global DataSphere, Nov 2018

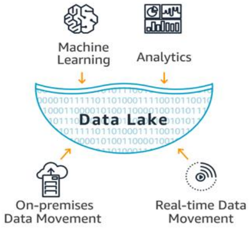

Input Device
Central Processing Unit
Control Unit
Arithmetic/Logic Unit
Memory Unit
Output Device


Challenges
Storage
Processing

Recap

Data Storage

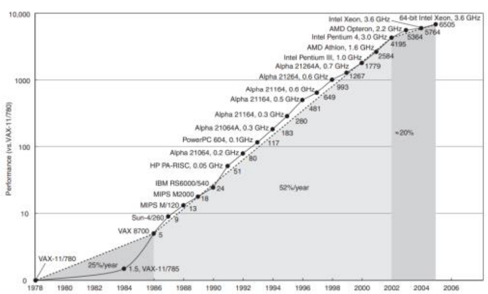




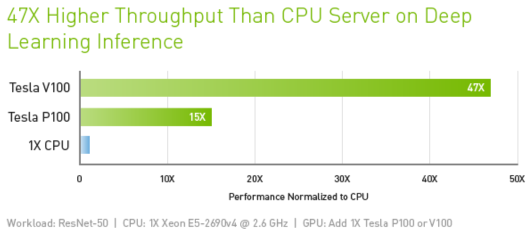
Amazon S3

STaaS

Data Processing



CPU Performance



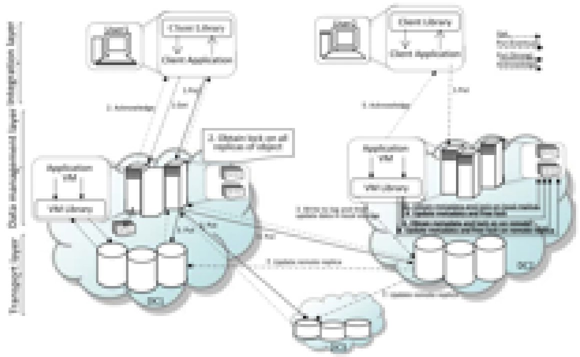
GPU Performance

SuperComputers

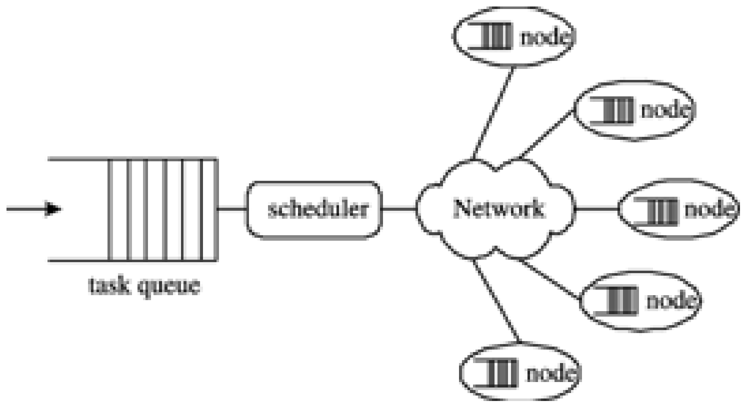
Cloud Computing

Two kinds of Big Data Opportunities

Storage



Processing



So, we have the cloud. But, how to store and retrieve data? How to process jobs?

Role of File Systems

Defragmentation

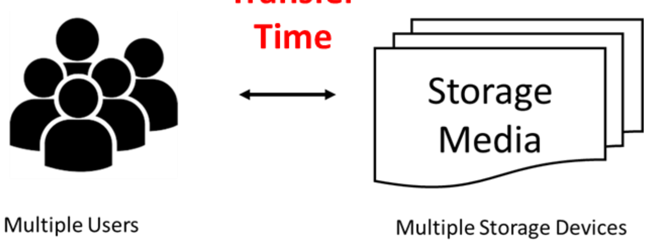
Compression

High Seek Time

Partitioning

Multiple OS, Multiple File Systems

High Data Transfer Time



File Allocation, Free Space Management

Space Utilization

Multi-Tenancy & data privacy

Permissions and Sharing

Data Variety

Naming Convention - Standards

File systems are key to handling data.

Variety of FS exist
NTFS, FAT, DOS, CDFS, NFS, ...

What is an operating system?

Yarn is now the [Apache Hadoop Operating System]()

Apache Hadoop

Open source platform for reliable, scalable, distributed processing of large data sets, built on clusters of commodity computers.

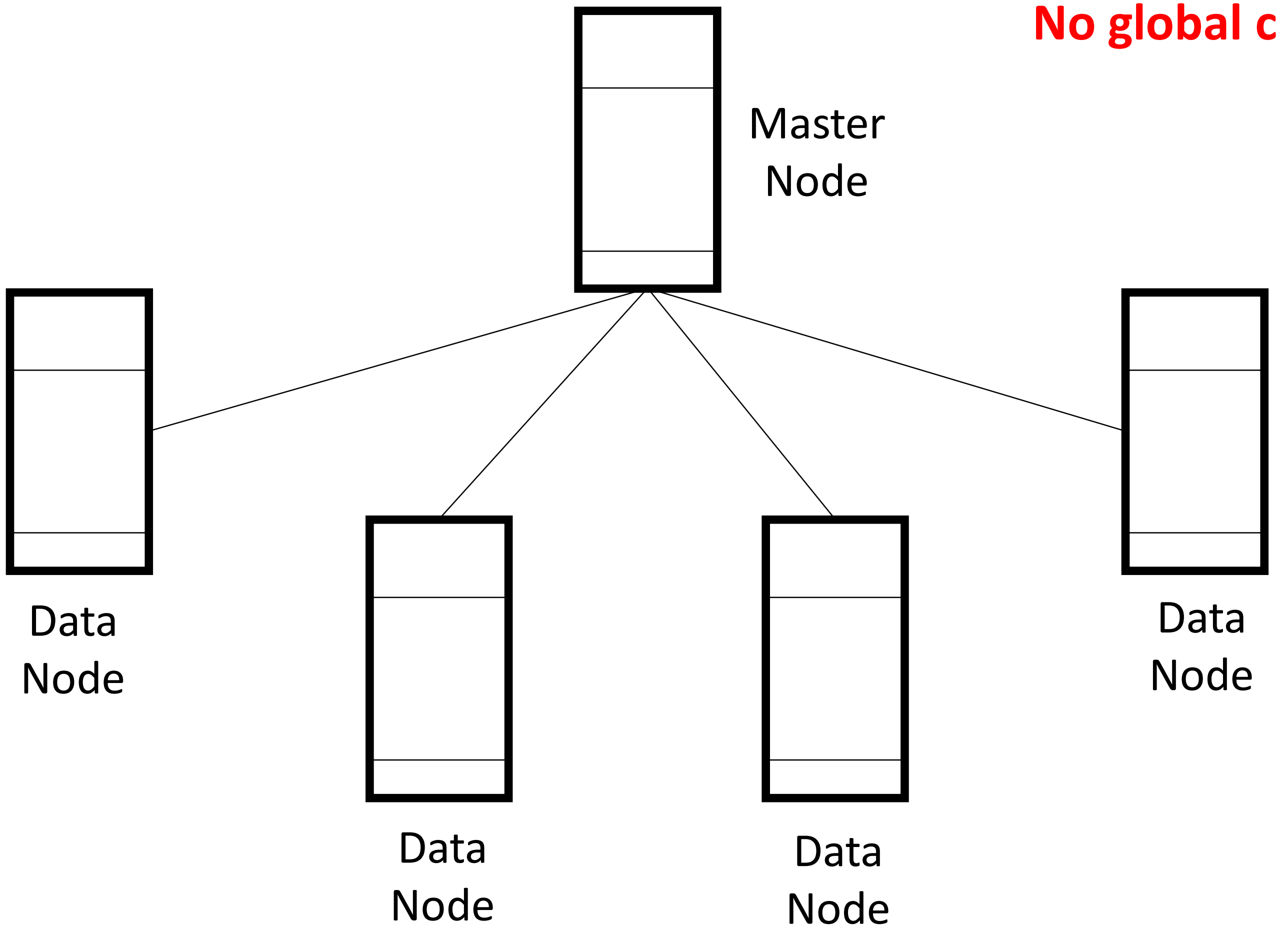
Distributed File Systems - Key Goals

- Distribution Transparency
- Location Transparency
- Scalability
- Fault Tolerance
- Efficient Data Access
  - Specifically designed for batch jobs
- “Write Once Read Many” (WORM) model

Several examples: Andrew FS, Network FS, HDFS

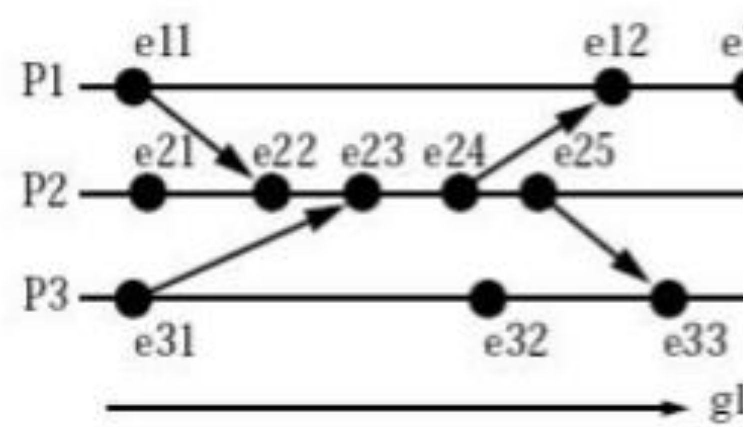
Distributed System

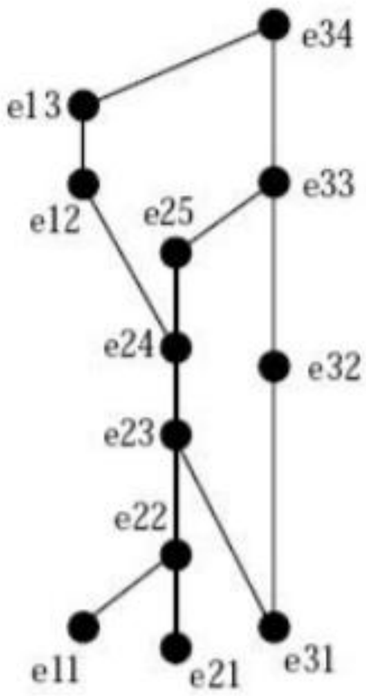
No global clock!



Master-Slave Architecture

Processes with Local Clocks

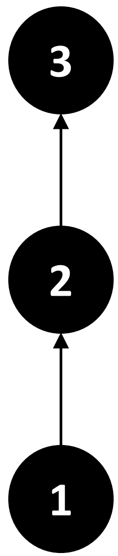




Virtual Time and Global States of Distributed Systems, Friedemann Mattern.

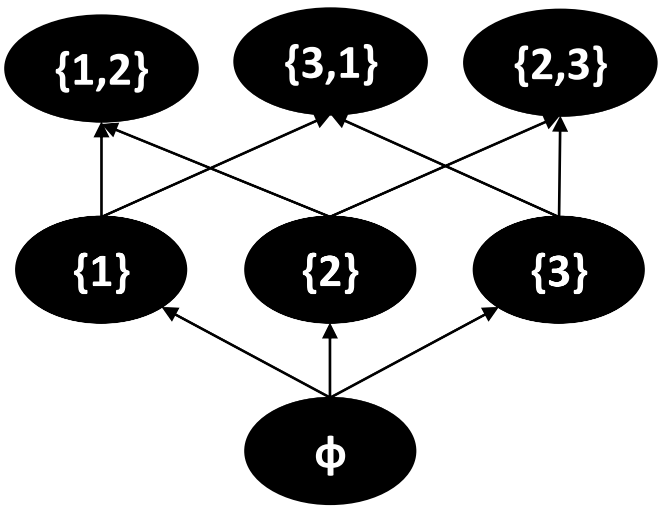
Total Vs. Partial Order

The Pair ({1,2,3}, <)



A strict total order.

The Pair ({{},{1},{2},{3},{1,2},{1,3},{2,3}}, ⊆)



Partially ordered under the ⊆ operation!

Reflexive, Transitive and Anti-symmetric

a<=a

a<=b and b<=c implies a <= c

a<=b and b<=a implies a = b

Hasse Diagram

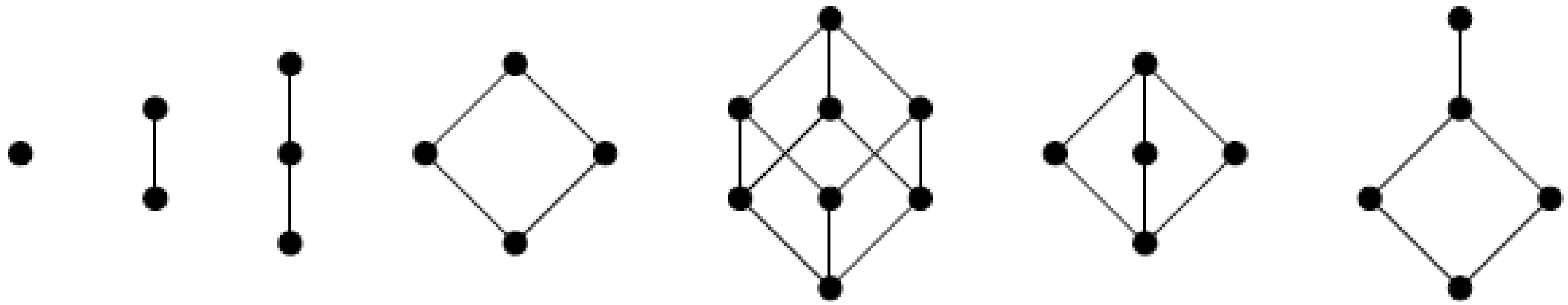
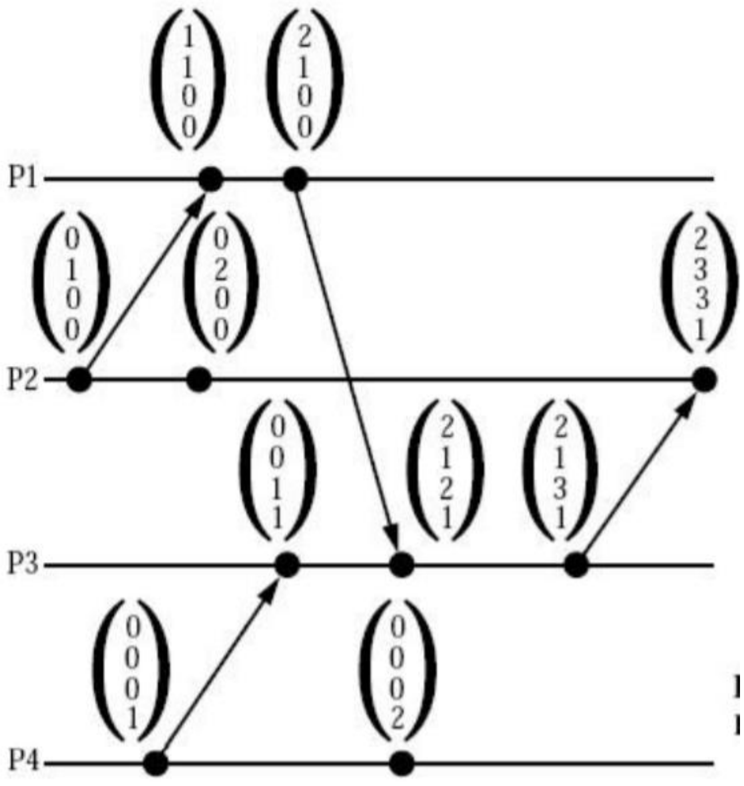


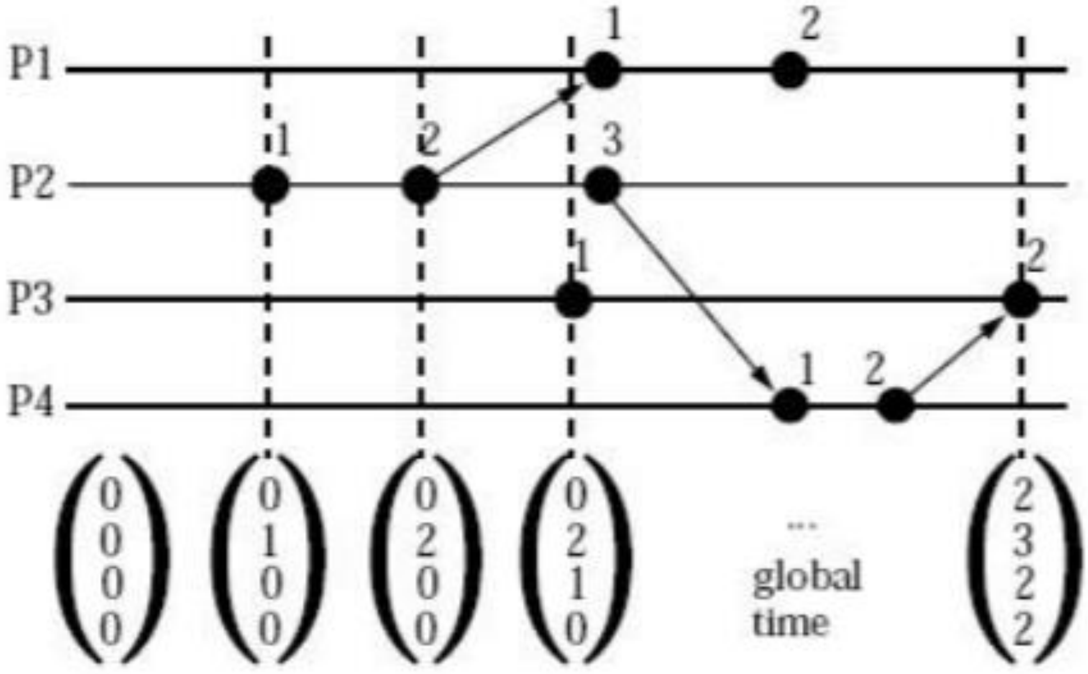
Image source: Static Program Analysis, Moller and Schwartzbach

Vector Time Stamps



- Local clock is incremented every time an event occurs.
- An external observer knows about all events.
- Global time knowledge can be saved as a vector, with one element per process.

Global Vector Time



Quiz

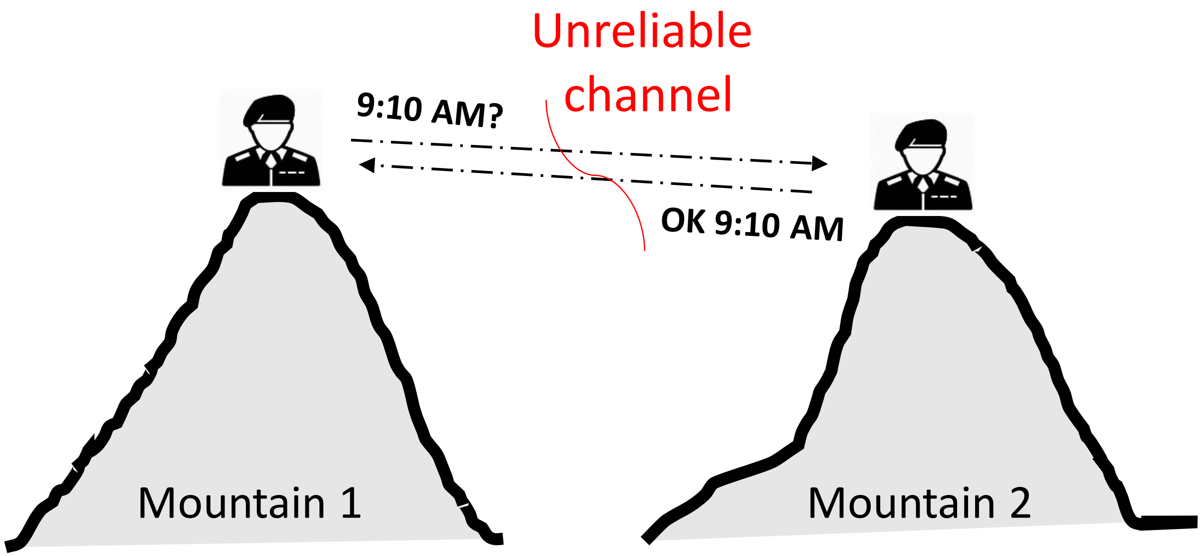
- Which of the below specify a strictly “**happens-before**” relationship between two event time stamps?
  - (2,0,0) → (3,0,0)
  - (2,2,1,3) → (3,3,2,4)
  - (1,2,1,2) → (1,1,2,2)
  - (3,3,2,4) → (2,2,1,3)

Efficient Implementations

- For large number of processes,
  - Disseminating time progress and updating clocks can cause serious overhead.
  - Need efficient ways to maintain vector clocks.
- Two popular techniques
  - Singhal–Kshemkalyani's differential technique
    - Few clock vector entries change between successive messages to same process.
  - Fowler–Zwaenepoel direct dependency technique
    - No vector clocks are maintained on-the-fly.
    - A process only maintains information regarding direct dependencies on other processes.

Chapter 3 of Distributed Computing Principles, Algorithms, and Systems, Kshemkalyani and Singhal.

Limitations



General's Paradox

Two generals must attack at the same time, or they die.

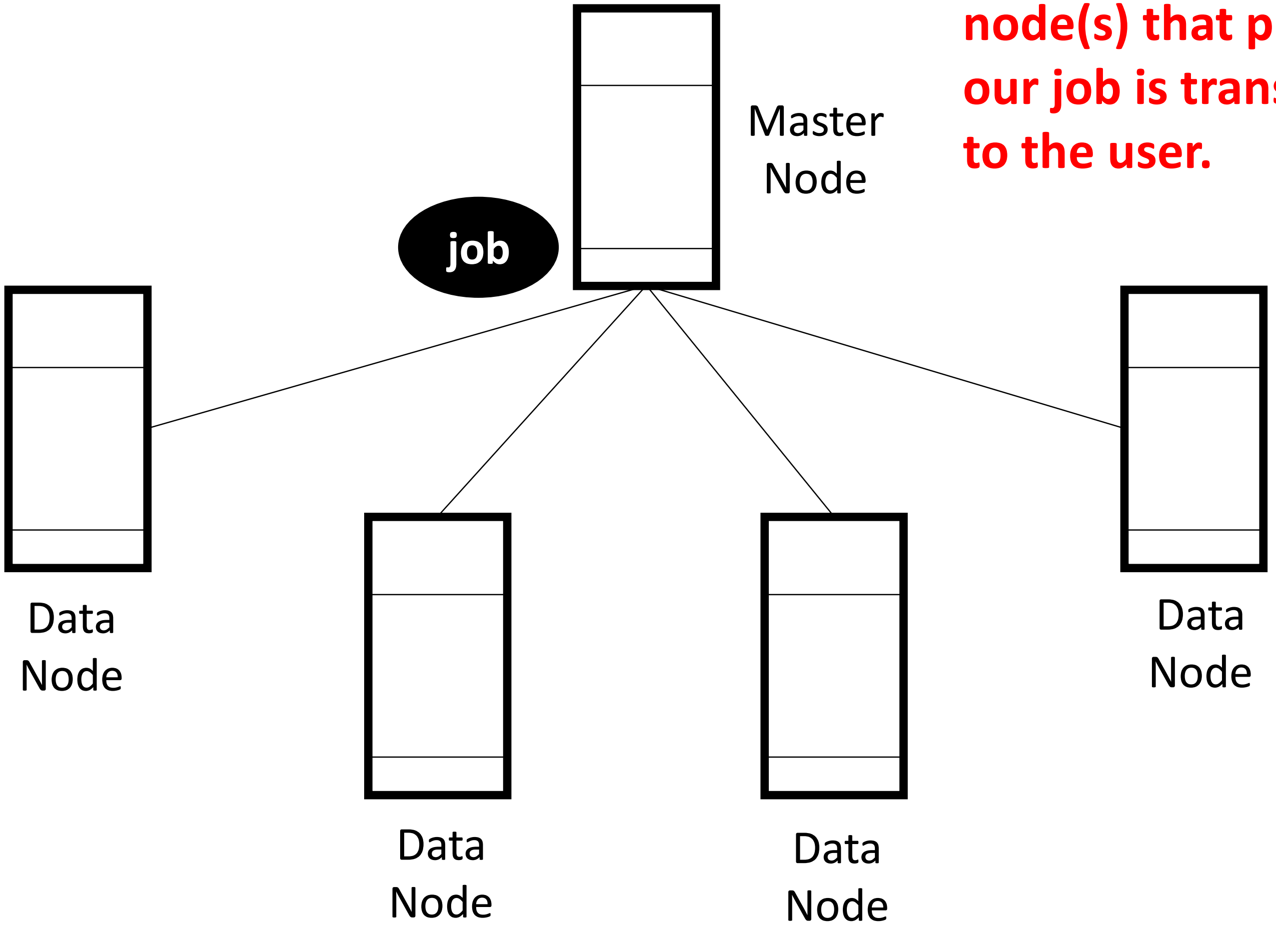
Is there a way to coordinate?

What if, two machines need to coordinate, but not necessarily at the same time?

Is it possible?

Yes! Transactions!! Two-Phase Commit Protocol.

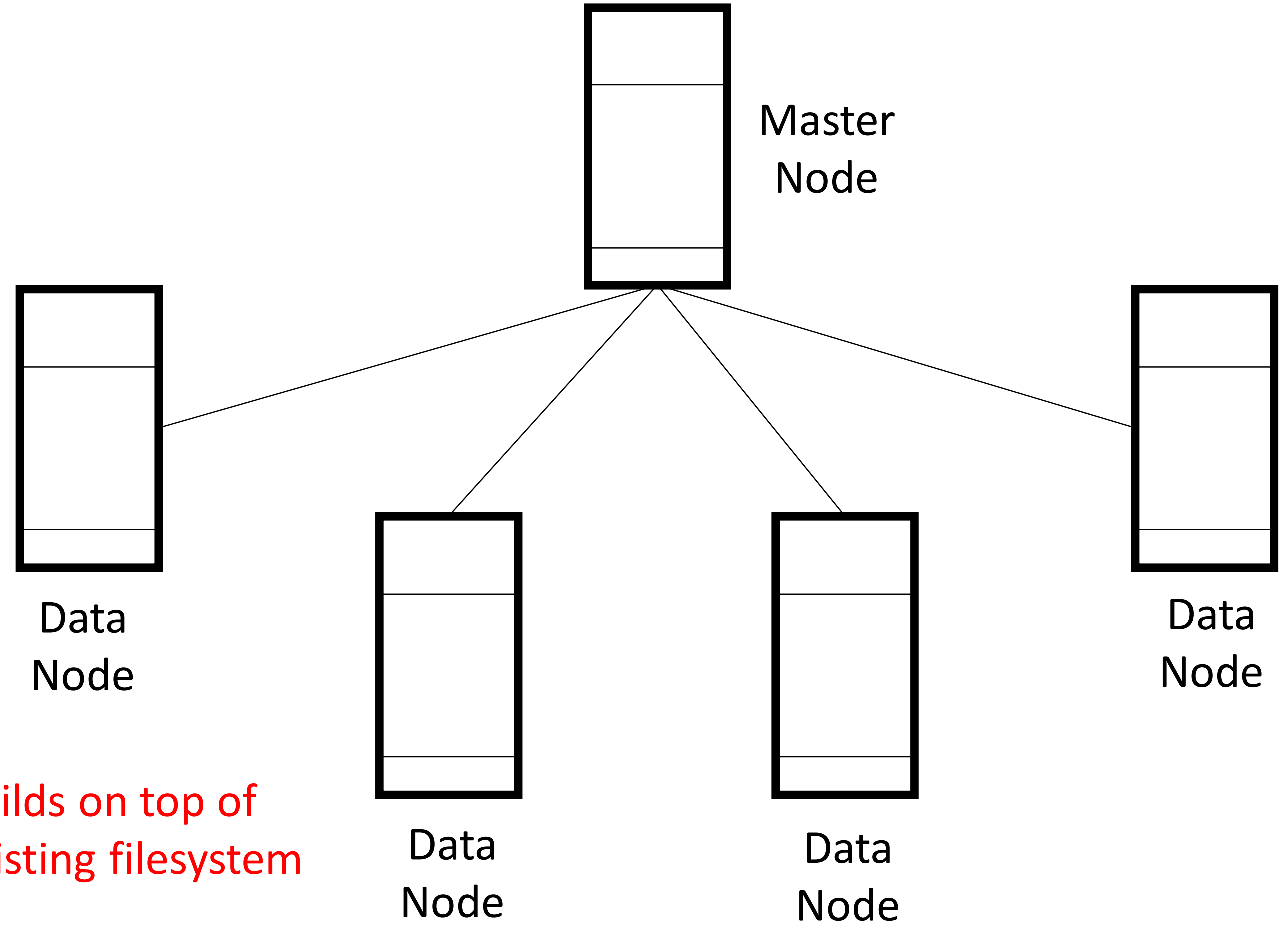
Distribution Transparency



node(s) that process our job is transparent to the user.

Master-Slave Architecture

Hadoop Distributed File System Architecture



Builds on top of existing filesystem

Master-Slave Architecture

Location Transparency

- Refers to uniform file namespace.

Example

```
hdfs  dfs  -cat  hdfs://nn1.cmi.ac.in/file1  hdfs://nn1.cmi.ac.in/file2
```

https://hadoop.apache.org/docs/r2.4.1/hadoop-project-dist/hadoop-common/FileSystemShell.html

HDFS

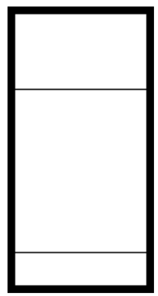
- HDFS commands are very similar to UNIX shell commands
  - ls
  - du
  - mkdir
- Some additional commands
  - copyToLocal
  - copyFromLocal

```
cd usr/data/
hdfs dfs -copyToLocal test/cmi.csv cmi.csv
```

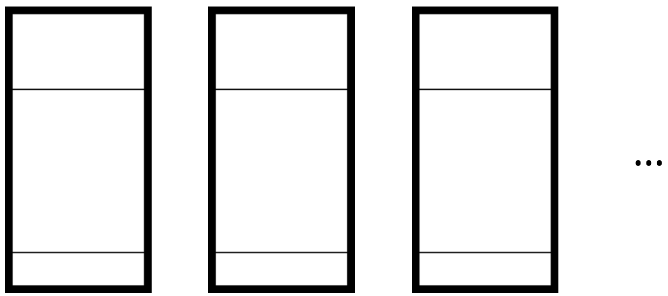
HDFS Commands

```
$ bin/hadoop fs -ls /user/joe/wordcount/input/
/user/joe/wordcount/input/file01
/user/joe/wordcount/input/file02

$ bin/hadoop fs -cat /user/joe/wordcount/input/file01
Hello World Bye World

$ bin/hadoop fs -cat /user/joe/wordcount/input/file02
Hello Hadoop Goodbye Hadoop
```

Scalability



Scale **up**
(add resources
to a single node)
Vertical Scaling



Scale **out**
(add more nodes)
Horizontal Scaling

With Hadoop, we can scale both vertically and horizontally.

Scale-up or Scale-out?

- What would you prefer and why?

https://www.microsoft.com/en-us/research/publication/scale-up-vs-scale-out-for-hadoop-time-to-rethink/

Scale-up or Scale-out?

- What would you prefer and why?
  - Depends on data size.
    - Majority of real-world analytic jobs process < 100 GB data.
    - Hadoop is designed for petascale processing.
    - An evaluation (done at Microsoft) across 11 representative Hadoop jobs shows that scale-up is competitive in all cases.

https://www.microsoft.com/en-us/research/publication/scale-up-vs-scale-out-for-hadoop-time-to-rethink/

Adding a New Data Node is Easy

- Prepare the datanode
  - JDK, Hadoop, Environment Variables, Configuration (point to master)
- Start the datanode
  - hadoop-daemon.sh start datanode
- Run disk balancer to if you wish to redistribute existing data.

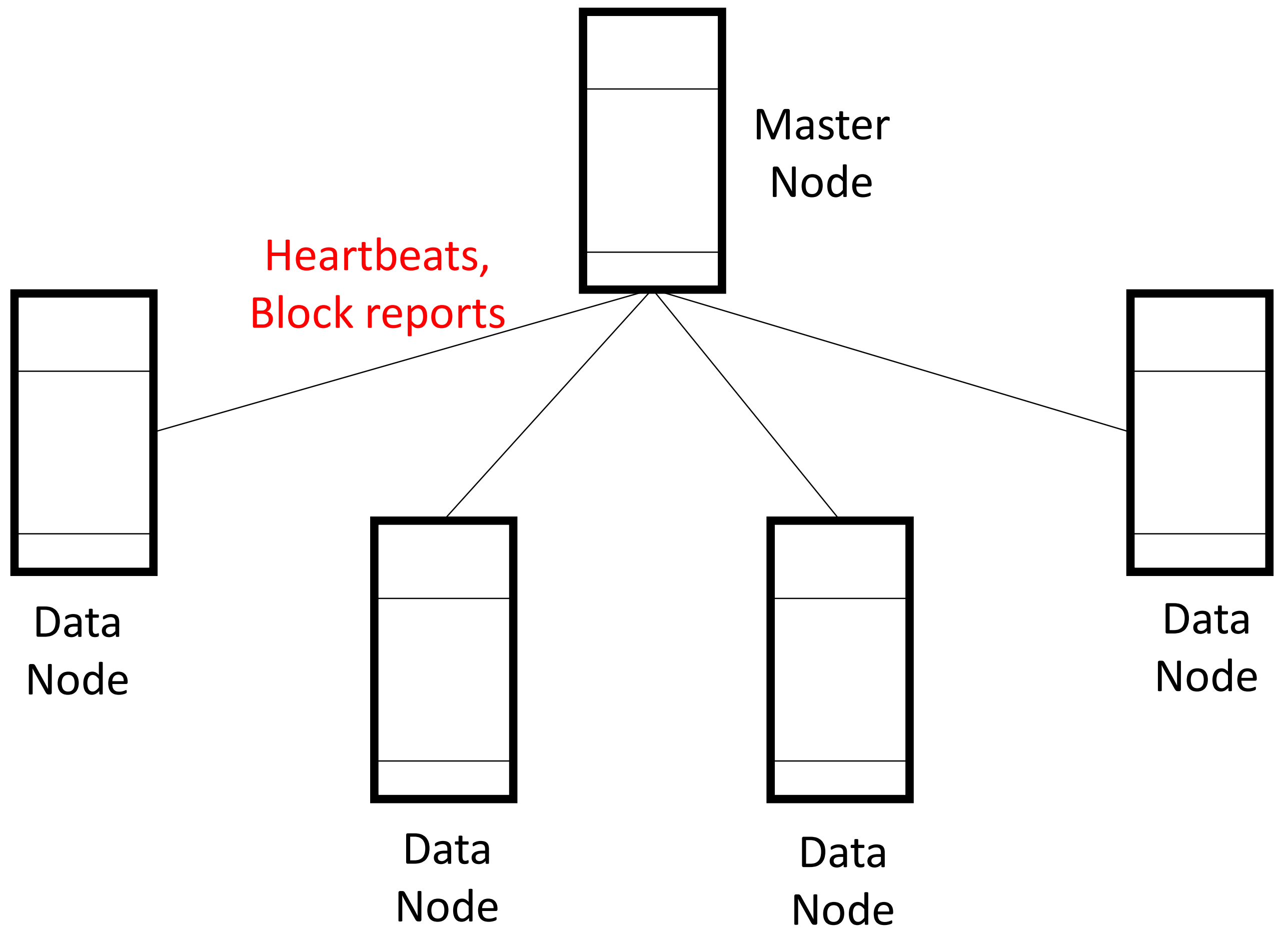
Fault Tolerance

- Typical clusters have 1000+ datanodes.
- Unfavorable Situations
  - Blocks of data may get corrupted.
  - Datanodes may go down.
  - Network links may go down.

Try This!

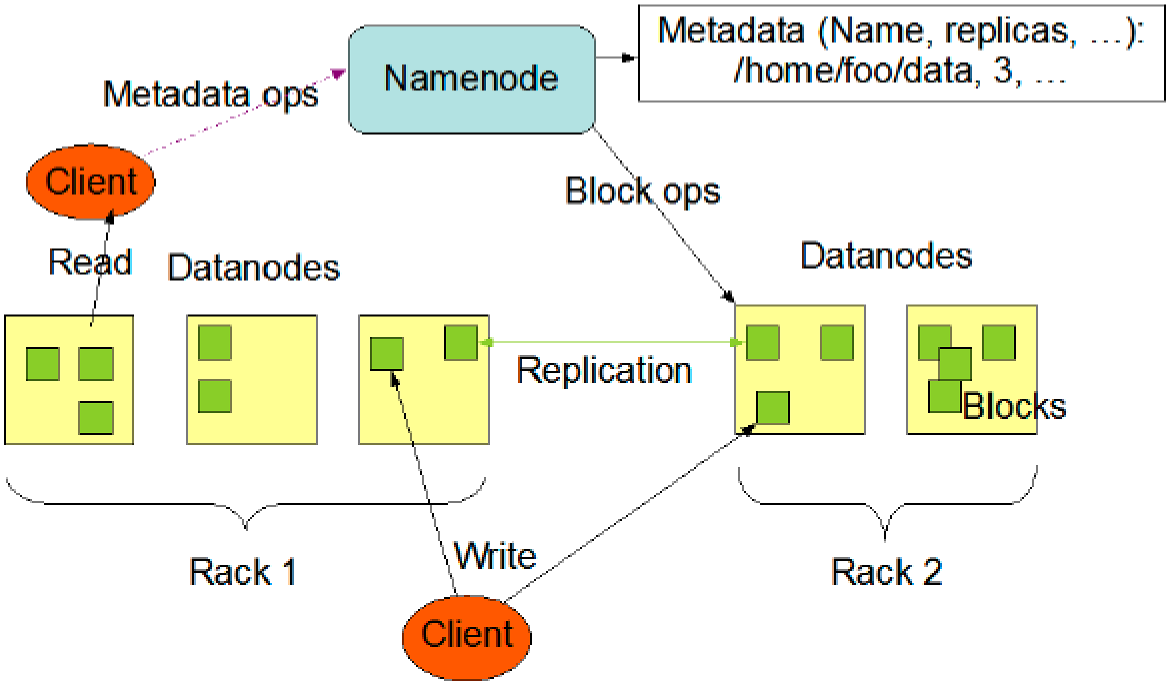
Assume we have a 1000 node cluster with each node having a single disk. Also, assume that the disk life is such that every disk fails in three years. How many nodes will be down on an arbitrary day due to disk failure?

Fault Tolerance



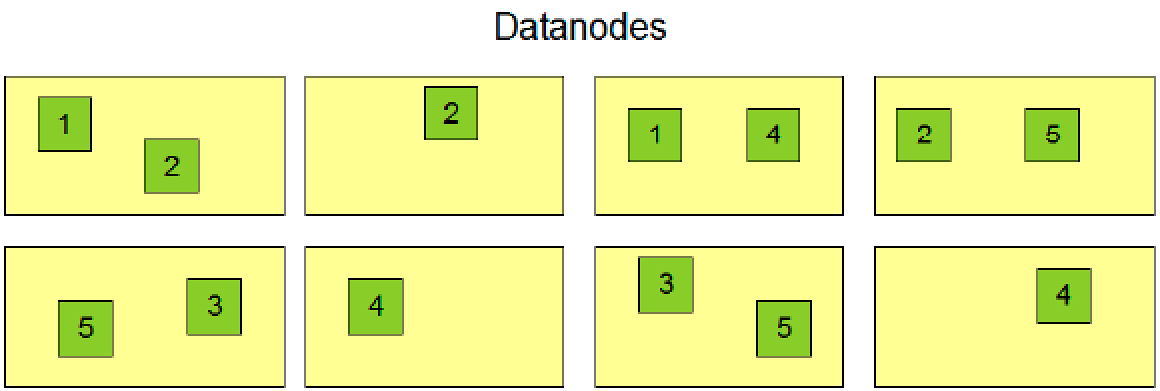
Master-Slave Architecture

HDFS Data Replication



Source: HDFS Architecture Guide, Dhruba Borthakur.

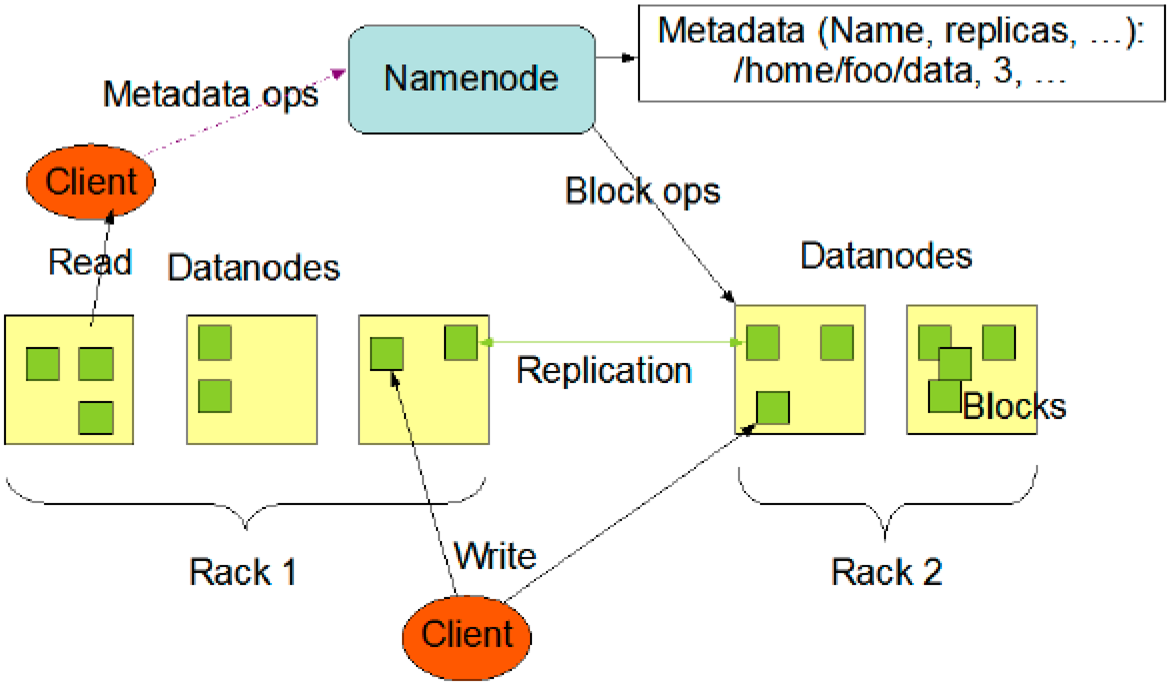
Replication



Single Point of Failure

Is namenode a single point of failure?

Hadoop 2.0 supports primary and secondary namenodes



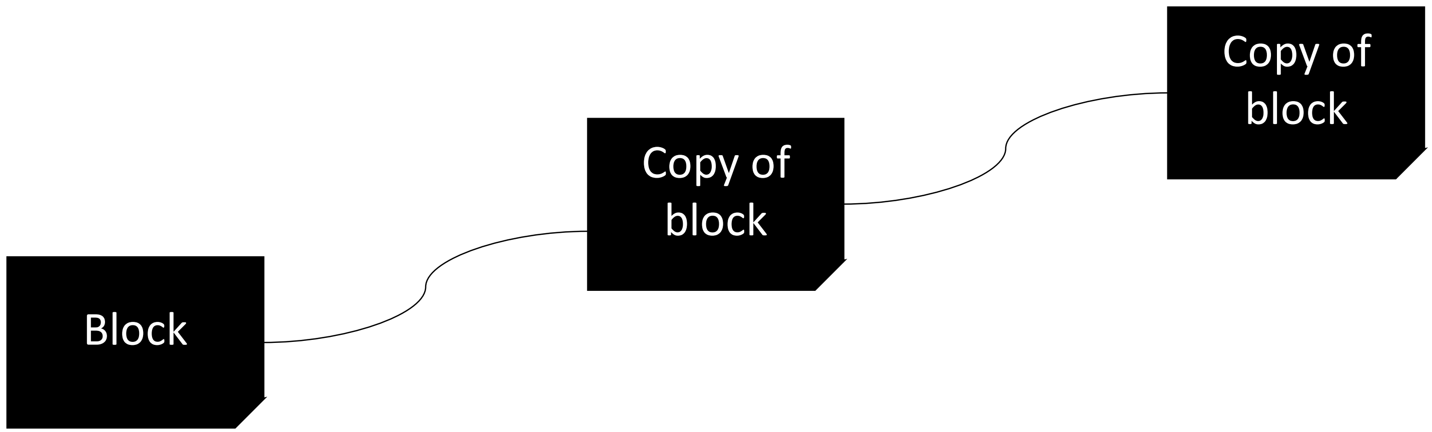
Source: HDFS Architecture Guide, Dhruba Borthakur.

Efficient Data Access

- Write Once Read Many (WORM) model

Write Once Read Many

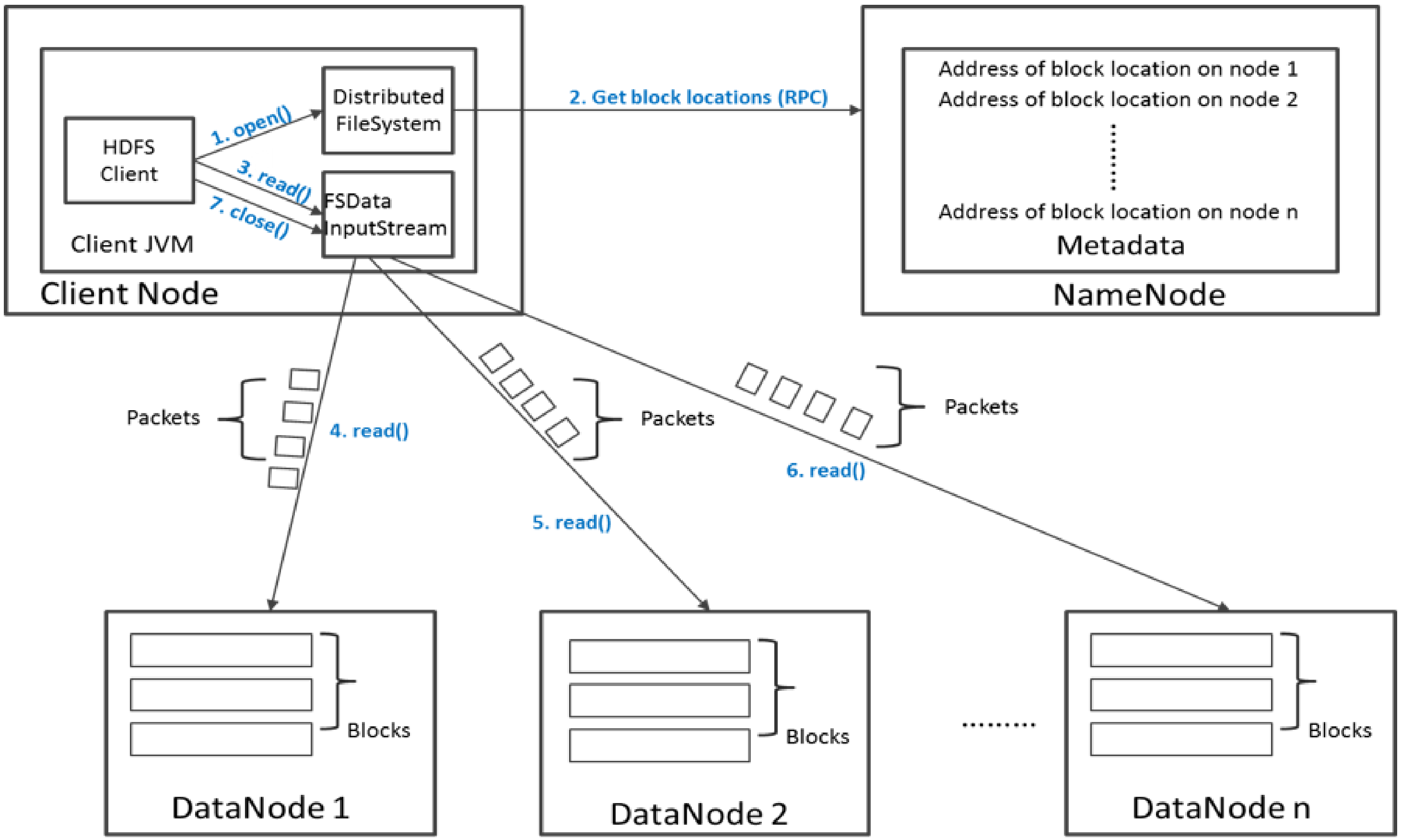
- Simplifies Data Coherency



Need to keep all the copies in sync.

- Designed for batch jobs

HDFS – Data Read Operation



Data Read Operation

- Client asks Namenode for block addresses
- Client accesses each block by accessing the datanodes **directly**.
- Since data is **accessed in parallel**, the reads are highly optimized.

Data Write Operation

- Namenode **provides the address** of the datanodes
- Client **directly writes** data on the datanodes
- Datanode will **create data write pipeline**
  - First datanode copies the block to another datanode, which intern copy it to the third datanode
- Datanodes send **acknowledgment**

Design Choices

- Default block size is 64 MB. Often used as is, or as 128 MB.
- How do you decide the right value for block size?

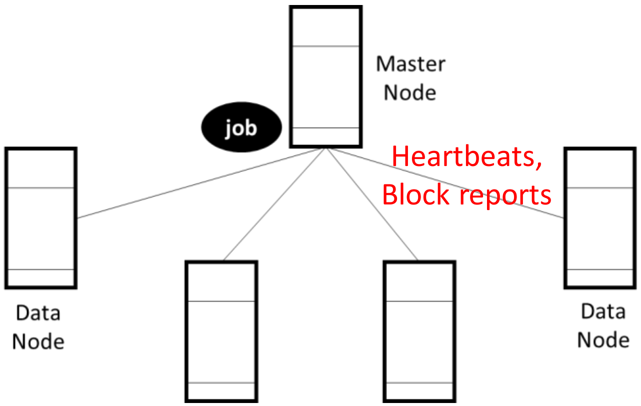
Design Choices

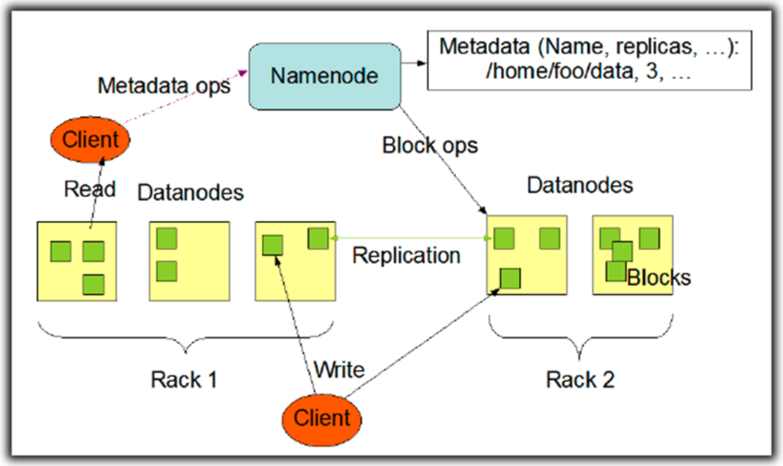
- Default block size is 64 MB. Often used as is, or as 128 MB.
- Block Size – Concerns:
  - Designed to handle large files (not small files, not even large number of small files).
  - For large number of small files, namenode needs to store too much metadata.
    - Solution: Sequence files.

Sequence Files

- Hadoop specific file format.
- Files consisting of binary key/value pairs.
- Three types:
  - Uncompressed
  - Record Compressed
  - Block Compressed

Summary





Distribution Transparency
Location Transparency
Scalability
Fault Tolerance

Efficient Data Access
“Write Once Read Many” (WORM) model